Microring Resonators for Cavity-Enhanced On-Chip Absorption Spectroscopy

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Abstract:

We demonstrate on-chip laser absorption spectroscopy using silicon microring resonators integrated with polydimethylsiloxane (PDMS) microfluidic channels. A 100 µm radius microring resonator with a $Q > 100,000$ is used to enhance the interaction length between evanescent light and a cladding liquid. We measure absorption spectra of less than 200 nL of N-methylaniline from 1460 nm to 1610 nm with 1 nm resolution and effective free space path lengths up to 5 mm. This work can help realize a completely on-chip spectroscopy device for lab-on-a-chip applications.

Summary of Research:

Optofluidic techniques where microfluidics are integrated with photonic components are gaining widespread use in biosensing and chemical analysis applications [1]. Incorporating advanced fluid handling techniques at the micron scale with highly sensitive photonic devices has the potential to provide compact, effective sensors for lab-on-a-chip tools. Absorbance-based optofluidic techniques are particularly attractive since they offer the potential to provide label-free spectral information for detection and identification of an analyte. The miniaturization of microfluidic devices, however, reduces the optical path length for absorption based sensors as compared to their macroscopic counterparts. A shortened optical path reduces the interaction length of light with a fluid and limits the sensitivity of a device and its ability to detect an absorbing specie. It has been shown that high quality factor cavities [2], can be used to enhance the interaction length between guided light and an analyte. In this work we demonstrate integrated absorption spectroscopy in the near infrared using microring resonators and microfluidic channels.

The proposed device is a silicon microring resonator covered by a microfluidic channel, as shown in Figure 1. We design the device so that the evanescent light traveling in the ring resonator interacts with the upper fluidic cladding. At resonance, light circulates many times within the ring which leads to a large enhancement in the interaction length between the evanescent field and the cladding liquid. Any losses present in the fluid will alter the quality factor and extinction ratio of the transmission resonance. By extracting the absorption contribution of an analyte to a resonance and repeating this process for many resonances over a range of wavelengths, an absorption spectrum for an analyte can be measured.

The device was designed to maximize interaction with the cladding fluid. The cross section of the ring and
waveguide are 450 nm wide by 250 nm tall which supports a single mode at 1.5 µm. The straight waveguides are oxide clad which provides a symmetric index profile to increase optical fiber input light coupling and also reduces waveguide losses. The ring resonators are exposed (uncladded) which allows maximum interaction of the evanescent light trapped in the ring with any subsequent fluidic cladding. The optical structure was fabricated using standard microfabrication techniques on a silicon-on-insulator wafer with a 3 µm buried oxide layer and 250 nm device layer. The devices were patterned with a JEOL electron beam lithography system and then etched using inductively coupled plasma etching, shown in Figure 2. The microfluidic channels were made from PDMS using soft lithography processes. A master mold for the microfluidic channels was made by patterning SU-8 channels with a thickness of 30 µm and width of 300 µm using contact lithography. PDMS was then poured over the mold and baked at 80°C for several hours. The PDMS fluidics layer and photonic chip were then oxygen plasma cleaned before a contact aligner was used to irreversibly bond the PDMS to our device chip. Finally, we connect Tygon tubing to the microfluidic channel inlets to allow fluid to be introduced into the channel.

The experimental procedure for extracting the spectral information of the analyte consists of tuning the wavelength of the input light source while recording the transmission of the bus waveguide for various fluids present in the microfluidic channel. Each resonance is then fitted to a theoretical model to extract the absorption contribution from the cladding fluid. The setup includes a tunable laser source (1460-1610 nm) which is coupled into our waveguides using a tapered lens fiber. Transmission through the device is collected with a microscope objective lens and focused onto a photo-detector. The fluids of interest are controlled by pressure driven flow from a syringe pump.

We demonstrate the ability to detect absorption features in an analyte by injecting N-methylaniline into the microfluidic channels. The analyte was chosen since the N-H bonds in N-methylaniline lead to an absorption peak near 1500 nm which is within the limits of our tunable laser. The absorption contribution from the analyte is determined by subtracting the intrinsic absorption measured while the device is air clad. The absorption spectrum of N-methylaniline measured using the ring resonator device is plotted in Figure 3 along with the absorption measured using a commercial spectrophotometer and there is very good agreement between the two curves.

The sensitivity of the device is related to the effective path length traveled by light circulating within the ring. The free space equivalent path length can be determined from the quality factor $Q$ of the ring resonance and is calculated to be $\sim 5$ mm. A straight waveguide without a ring would have to be $\sim 20$ times longer to achieve the same sensitivities which shows that microring resonators can be effectively used to increase the sensitivity of a miniaturized on-chip device.

References:


Figure 3: Spectrum for N-Methylaniline measured with our microring device and spectrophotometer.